Quality of Archived NDBC Data as Climate Records

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Abstract- **The National Data Buoy Center (NDBC) traces its beginning to the formation of the National Data Buoy Development Program in 1967, which consolidated approximately 50 individual programs conducted by a variety of ocean-oriented agencies. Today, NDBC operates three major buoy networks. First, the traditional *weather fleet* consists of over 100 moored buoys covering the coastal waters of the United States, including the Great Lakes, Hawaii and Alaska. Second, the Deep-ocean Assessment and Reporting of Tsunamis (the National Oceanic and Atmospheric Administration's DART®) Program operates 39 stations that detect and instantly report anomalies in ocean pressure associated with potential tsunami-generating seismic activity. Third, the Tropical-Atmosphere Ocean (TAO) array of climate monitoring platforms covers a wide swath of the equatorial Pacific. In this paper, we assess the traditional weather fleet as a resource for climate monitoring, and we do so in two ways. Both involve scrutinizing weather fleet records exceeding 20 years duration. We assess these according to the ten climate monitoring principles recommended by the U.S. National Research Council. We observe that NDBC has implicitly considered most, if not all, of these principles in the design, maintenance, improvement and expansion of the NDBC moored buoy fleet. Focusing on two stations in the Pacific Ocean, 46035 and 46042, we demonstrate NDBC's adherence to sound network management, careful archiving and description of metadata, steady development of comprehensive automated quality control procedures, giving users ease in data access, addressing issues of complementary data, historical significance and continuity of purpose. One area requiring strengthening remains a need for NDBC to build into its systems long-term climate requirements. Next, we propose a new method for reflecting climatic change over the oceans. The wave energy spectrum, which all NDBC weather buoys routinely report hourly, contain a significant amount of information regarding the origin, intensity and duration of ocean storms. Such measurements are produced from simple accelerometers coming from a mature, stable technology. We show that records of spectral energy density at low frequencies — for wave periods exceeding 20 seconds — suggest climate change signals. This is demonstrated with data collected from station 46042 in Monterey Bay, California. Both assessments clearly indicate that the NDBC network of weather monitoring buoys are a valuable national resource for climatologists, meteorologists and oceanographers interested in marine surface fluctuations on decadal and longer durations. We note areas where small improvements in calibration techniques will likely yield large gains in confident assessment of climate change.**

I. INTRODUCTION

For over 40 years, the National Data Buoy Center (NDBC) and its preceding organizations, the National Data Buoy Development Program and the National Data Buoy Office, have deployed automated meteorological and oceanographic data acquisition stations for the National Weather Service. Near real-time measurements coming from these remote systems give weather forecasters information that is, at times, the only information available for issuing critical marine warnings of severe weather threatening life and property. NDBC archives its records and posts them on its very popular Web site. These data have become a resource for engineering and architectural design, forensics, renewable energy resource assessment and general climate research. In this paper, we evaluate the utility of archived NDBC measurements for climatological investigation within the context of the ten principles of climate monitoring proposed by Karl *et al.* [1] and later adopted by the National Research Council in 1999 [2]. We also examine the quality of standard NDBC data for climate assessment.

Over the past 30 years, the NDBC weather buoy fleet has grown from less than a dozen off the Atlantic coast to over 100 buoy stations covering the whole U.S. coastline, including Alaska and Hawaii. Some of the early stations have data records long enough for researchers to incorporate them into climate research. An obvious question becomes this: Are standard NDBC records good enough? In this paper, we show that some NDBC time series should be acceptable for general climate studies provided users are willing to carefully inspect and edit individual records.

In this preliminary study, we focus on two stations, representative of the rest of the weather fleet, yet unique. First, we examine the 20-year standard meteorological records from the Bering Sea, station 46035, in one of the harshest environments of the NDBC network. Average hourly wind speed there exceeds 8 meters per second and air temperatures fall below freezing for a significant portion of each year. Second, we examine the 20-year wave record from station 46042, in Monterey Bay, California. We

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present a new, possibly highly efficient, method for monitoring the climate of the entire Pacific Ocean using a single directional wave station.

NDBC Adherence to Climate Monitoring Principles

The National Research Council [2] recommended that persons, offices and agencies involved in climate research and assessment strive to apply ten climate-monitoring principles to their systems. These principles, first proposed by Thomas Karl *et al.* [1] call for scientists, engineers, program managers and administrators to act as follows: (1) to assess the impact of new systems or changes to any climate monitoring network; (2) to conduct parallel testing of old and new systems for a sufficiently long time before replacing old systems with new ones; (3) to comprehensively document each observing system, including procedures for operating it; (4) to assess routinely the quality of data obtained; (5) in formulating strategic plans, to anticipate the use of data in developing environmental, including climatic, assessments and impacts; (6) to preserve observing systems that have provided consistent data sets over a period of decades; (7) in establishing new stations, to give highest priority to data-sparse regions, regions sensitive to change, and to key measurements with inadequate temporal resolution; (8) to give network designers, operators, and instrument engineers climate monitoring requirements at the start of network design; (9) to maintain a stable, long-term commitment to observations; and, finally, (10) to develop data management systems that facilitate access, use, and interpretation of data and data products by all kinds of users.

NDBC's primary mission is to deploy survivable instruments in remote, harsh environments to obtain accurate, immediate measurements for dissemination to weather forecasters and to persons operating in the field. All weather fleet instruments are calibrated prior to deployment and all candidate replacement sensors must meet strict National Weather Service standards for accuracy, reporting range and reporting resolution; however, instruments are not post calibrated, making it impossible accordingly to scale records as is usually done with climate records. NDBC engineers carefully evaluate upgrades to older model instruments and new techniques in NDBC laboratories, at NDBC's outdoor Michelena Test Facility and eventually at sea during specially designed dual sensor deployments. Formal engineering test plans guide all tests. Successful upgrades, improved designs and new techniques are documented in user's manuals and engineering drawings signed by NDBC personnel. Members of the NDBC Data Assembly Center (DAC), comprised of a team of trained, conscientious meteorologists and oceanographers, monitor the incoming data stream around the clock, every day of the year, a routine initiated July 1, 2005. The NDBC Web site provides a rich resource for data users, who can easily pull very long records using simple file transfer protocol procedures.

NDBC Wave Measurements

We review NDBC's technique for estimating directional waves. A directional wave spectrum $S(f,\theta)$ of the following form, a function of frequency f and wave direction θ, is sought:

$$S(f,\theta) = C_{11}(f)D(f,\theta).\tag{1}$$

$C_{11}(f)$ is the non-directional sea surface displacement spectrum. After Longuet-Higgins, Cartwright and Smith [3], we write the spreading function $D(f,\theta)$ as a Fourier series:

$$D(f,\theta) = \frac{1}{\pi}\left\{\frac{1}{2} + \sum_{1}^{\infty} r_n \cos[n(\theta - \theta_n)]\right\}.\tag{2}$$

With measurements of sea surface elevation and slopes, the first two terms of the series are used. Thus,

$$D(f,\theta) \cong \frac{1}{\pi}\left\{\frac{1}{2} + r_1 \cos[\theta - \theta_1] + r_2 \cos[2(\theta - \theta_2)]\right\}.\tag{3}$$

In the above equation, the frequency-dependent spreading functions r_1 and r_2 range from zero to unity, a value of one indicating that all wave energy at a particular frequency f is associated with a single direction θ. The directions θ_1 and θ_2 represent the direction, counter-clockwise from east, toward which a wave travels. The former is associated with mean wave direction; the second is primary wave direction. In changing from Cartesian to nautical coordinates, we convert θ_1 and θ_2 to α_1 and α_2, respec-

tively, representing waves coming from, from a direction clockwise from north. Complete description of directional wave measurements using NDBC buoy measurements is given in references [4] and [5].

Using a vertically stabilized accelerometer, as in the Datawell Hippy 40 Mk 2 motion sensor, the non-directional, displacement spectrum $C_{11}(f)$ is obtained from the spectrum of accelerations C_{11}^m, corrected by a noise correction function NC, a heave-hull transfer function R^{hH} and a conversion function to integrate acceleration into displacement. We write it as follows:

$$C_{11}(f) = \frac{C_{11}^m(f) - NC}{(2\pi \cdot f)^4 (R^{hH})^2}$$

(4)

For the 1,720-kilogram, 3-meter hull, R^{hH} is near unity for all frequencies below about .3 hertz; however, for the 12-m hull, the transfer function corrects for the significant mechanical filtering of higher frequency waves by the 87,500-kilogram mass of the buoy.

The frequency-dependent wave energy spectrum allows analysts to focus on selected frequency bands. Herein we examine swell energy of period 20 seconds or more, that is, frequencies up to .05 hertz. Storms at sea — tropical and extra-tropical — generate 20-second waves when wind blows at a speed of least 15.6 ms^{-1} based on the relation for deep-water group celerity $c_g = g/(2\pi f)$, g being the acceleration of gravity. Moreover, there must be a straight, uninterrupted fetch of about 450 km for about 23 hours. With this condition in mind, we focus on wave spectra for which the peak wave frequency f_p is no more than .05 hertz, and from these we compute two wave heights. The first wave height is the well-known H_{m0} defined as follows:

$$H_{m0} \equiv 4\sqrt{\int_0^\infty C_{11}(f)df} \cong 4\sqrt{\sum_{.04\,Hz}^{.40\,Hz} C_{11}(f)\Delta f}$$

(5)

The approximation on the right of (5) arises after linearly interpolating whatever spectrum we are using to the frequencies from 0.04 and 0.40 hertz, with a uniform frequency bandwidth of .0.01 hertz. This is necessary because of changes in wave processor at 46042. We use NDBC's original frequencies in this report and not those of the Digital Directional Wave Processor (DWPM), which was introduced in the late 1990s. We also define a low frequency wave height H_{low} as follows:

$$H_{low} \equiv 4\sqrt{\sum_{.04\,Hz}^{.05\,Hz} C_{11}(f)\Delta f}$$

(6)

This will be used in examining data from 46042 in section III.

II. STATION 46035 BERING SEA

Fig. 1: The 12-meter discus buoy, Station 46035, in the Bering

NDBC has always placed a 12-meter discus buoy in the Bering Sea except for a 10-month period starting October 2001, when a 6-meter boat-like NOMAD hull was used. Owing to the heavy weather in that region, the 12-m hull remains the preferred platform, even though on February 9, 2001 one such hull capsized during a storm. Depth at the station exceeds 3,600 meters.

Table I gives a brief history, including mooring position, hull type, payload and selected sensor outages, denoted by zeroes. The different payloads reflect the NDBC commitment to steady improvements. NDBC placed the first General Service Buoy Payload (GSBP) in the field in 1975, representing a major milestone because it sent real time measurements via Geostationary Operational Environmental Satellite (GOES). Magnavox delivered the first Digital Acquisition and Control Telemetry (DACT) payload to NDBC in 1982, its chief advantage being low power consumption. NDBC developed the PC-compatible payload, Multifunction Acquisition and Reporting System (MARS) payload in the 1990s and has since deployed it at 46035.

TABLE I. STATION 46035: BERING SEA (0 denotes sensor outage).

Period		Location		Hull	Payload	Sea level pressure	Wind speed	Wave height and period	Air temperature	Sea surface temperature
from	To	° N.	° W.							
Date		Note								
09/85	03/87	57.0	177.7	12m	GSBP	1	1	1	1	1
04/87	04/87	57.0	177.7	12m	GSBP	1	0	1	1	1
05/87	06//87	57.0	177.7	12m	GSBP	1	1	1	1	1
06/20/87		Buoy retrieved for refurbishment and electronics upgrade								
08/87	01/90	57.0	177.7	12m	DACT	1	1	1	1	1
02/90	08/90	57.0	177.7	12m	DACT	1	1	1	1	0
09/90	11/94	57.0	177.7	12m	DACT	1	1	1	1	1
12/94	12/94	57.0	177.7	12m	DACT	1	1	1	0	1
01/95	12/98	57.0	177.7	12m	DACT	1	1	1	1	1
01/99	02/99	56.9	177.8	12m	DACT	1	0	1	1	1
03/00	02/01	56.9	177.8	12m	DACT	1	1	1	1	1
02/9/01		12-meter discus capsized in high seas								
10/01	07/02	57.1	177.7	6m	MARS	1	1	1	1	1
07/02	06/03	57.1	177.6	12m	MARS	1	1	1	1	1
06/3/07		12-meter discus retrieved for refurbishment in Dutch Harbor, Alaska								
09/07	present	57.1	177.6	12m	MARS	1	1	1	1	1

An example of the quality of NDBC records is found in Fig. 2, obtained from station 46035. The data were pulled directly from the NDBC Web site and practically no data editing was required. The figure gives 153,743 hours of air and water temperature for the period covering September 13, 1985 to December 31, 2006. Plotted over the data is a first order regression curve indicating general warming in the Bering Sea. The slope of the lines represents an annual increase of 0.045°C per year (/yr) for air temperature and .040°C/yr for water temperature. These increases are consistent with climate studies of the Bering Sea, such as provided by Trenberth *et al.* [6], who have indicated that sea surface temperatures in the Bering Sea have risen approximately 0.7°C from 1950 to 1999, 0.014°C/yr over that period. The similarity of air and water temperature from the station, to 0.005°C/yr provides much needed scientific repeatability. Moreover, NDBC always deploys dual air temperature sensors, providing further confidence that the archived temperatures are accurate. Time series from both air temperature sensors are not available from the NDBC Web site but it is standard procedure for the DAC to monitor both sensors for differences. Additionally, the failure rate of thermistors is quite low. Monthly average temperatures are similar, as seen in Fig. 3. Slope of monthly air temperature is 0.038°C/yr; slope of monthly water temperature is 0.033°C/yr, which is closer to the value from Trenberth *et al*. [6] than are slopes associated with raw, hourly measurements`.
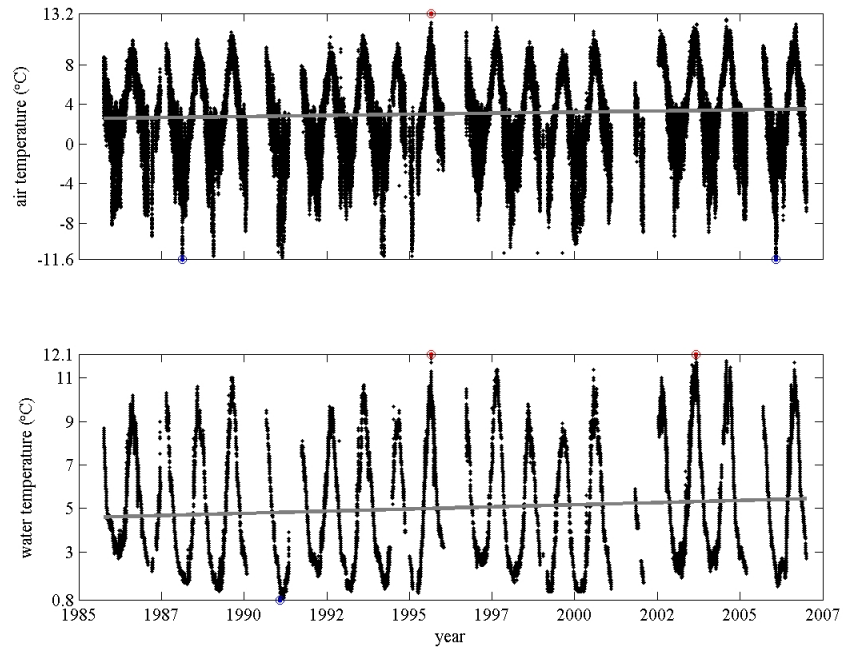
Fig.2: Station 46035 temperature records. Upper panel: air temperature. Lower panel: sea surface temperature. Red and blue marks are the maximum and minimum, respectively, denoted on the *y*-axes.
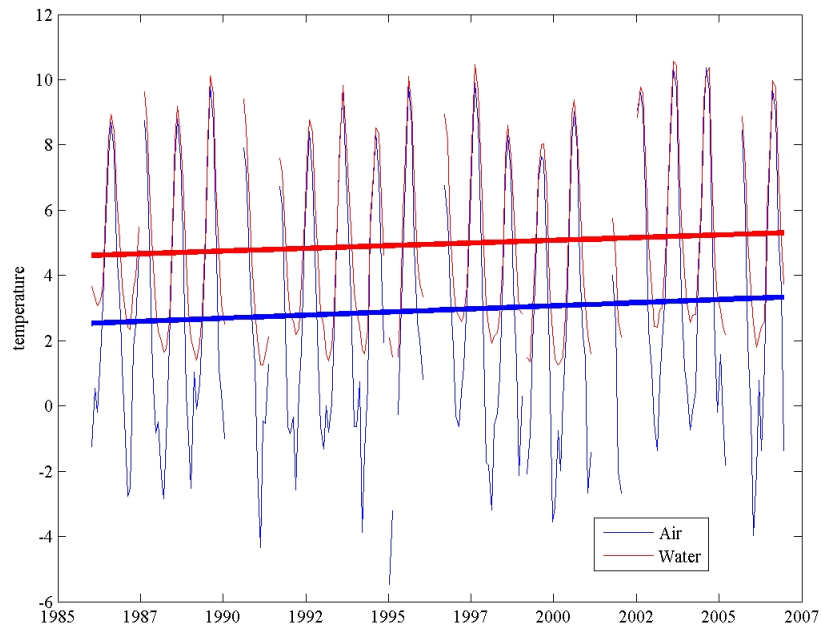

Fig.3: Station 46035 monthly temperatures in °C with first order regression lines.

Analysis of the other records from 46035 reveals varying changes. Wind speed increased over 20 years by 0.059 (ms^{-1})/yr. Barometric pressure increased slightly, 0.060 hPa/yr, which is but five hundredths of a percent of the range of air pressure in the record. Significant wave height has declined insignificantly -0.003 m/yr; however, we should use wave heights from a 12-m hull cautiously, due to its large mass, which tends to filter higher frequency waves. Recently, NDBC implemented an automated quality control check that truncates all directional wave spectra from 12-m buoys above 0.2 hertz. Since the average wind speed in the Bering Sea exceeds 8 ms^{-1}, an increase in wind may not be reflected as an increase in measurable waves because the increased

wind will likely be reflected in waves with periods less than five seconds. Regarding waves at periods higher than five seconds, we must realize that the Aleutian island chain acts as a physical barrier to many waves generated south of it and that the Bering Sea provides insufficient fetch for long period waves. We look at another station to assess wave measurements.

III. STATION 46042 MONTEREY BAY

The 3-meter directional wave station in Monterey Bay, moored in 2,100 meters deep water near 36.8°N 122.4°N, has always contained a Datawell Hippy 40 Mark II pitch-roll-heave sensor. The buoy location gives a vantage from which oceanographers

Fig. 4: The 3-meter discus buoy, Station 46042, in Monterey Bay with sea lion cage

can monitor swell waves arriving from distant storms within a sector from bearing 135°N clockwise to 355°N, oftentimes swell waves from thousands of miles away, as documented by Mettlach *et al.* [7]. The coastline east of the station provides a definite quality control tool, allowing analysts in the DAC easily to cull measurements erroneously representing swell coming from land. We observe that the level of long period, swell-wave energy arriving at this buoy has very likely increased in magnitude since the establishment of the station in 1987, arguably a consequence of increased storm activity over the world's oceans. However, the wave record from 46042 is not without problems so we make this attribution cautiously.

In Table II, we see the reason for three distinct blocks in the wave record from 46042, seen in Figs. 6 and 7. Both the operational mode of the Hippy wave sensor and the onboard wave pro-

TABLE II
STATION 46042: MONTEREY BAY

Period		Payload	Wave	Hippy
from	to		processor	mode
12/87	10/94	DACT	DWA	acceleration
10/94	10/04	DACT	DWA	displacement
10/04	Present	ARES	DWPM	acceleration

cessor give distinct characteristics to the measurements. The Hippy in acceleration mode acquires raw voltages from the Hippy's vertically stabilized accelerometer. Displacement mode electronically double integrates accelerations to give vertical displacement of the buoy.

Two types of payloads have been installed on 46042. The acronym ARES stands for Acquisition and Reporting Environmental System, a payload developed for NDBC in 1999 and 2000. It allows processing of more sensors than does the DACT. There have also been two wave processors used at 46042. The DACT Directional Wave Analyzer (DACT-DWA) produces wave spectra over wave frequencies from 0.03 to 0.35 hertz in increments of .01 hertz. The Directional Wave Processing Module (DWPM), the latest NDBC wave processor for the Hippy uses three data acquisition periods: 10 minutes for short-period waves, 20 minutes for intermediate-period waves and 40 minutes for waves in the swell range. It also produces 47 irregularly spaced frequency bands from 0.0325 to 0.4850 hertz. Users can find specific information about NDBC payloads and wave processors, as well as data reports, at the NDBC Web site http://www.ndbc.noaa.gov.

The directional wave station in Monterey Bay has provided one of the longer and better wave records in the NDBC weather fleet. It is a 3-m buoy with a Hippy 40 in deep water. Deep water allows us to disregard the effects of wave refraction and to obtain true deepwater wave directions. The Datawell Hippy has been used in many national wave-monitoring programs and has a long history of satisfactory performance. The 3-m buoy is large enough to support several sensors yet small enough to respond to 2-second waves. However, NDBC has unknowingly violated some of the principles of climate monitoring with this station, as we will show. Changes in mode and wave processor cast some doubt on the accuracy of data from the station, at least to the quality required for making plausible conclusions about changes in wave climate. Nevertheless, thoughtful data analysis allows us to recover a sensible, consistent record. We will need to analyze other long records from West Coast stations to support our tentative conclusions.

We hypothesize that from this single directional wave station, it is possible for analysts to monitor the climate of the Pacific Ocean remotely. The number and intensity of Pacific storms is manifest in the level of long-period swell wave energy imparted to the ocean surface by storm force winds. Wave energy directed toward the Monterey peninsula from anywhere in the Pacific Ocean will eventually arrive there. Oceanographers have developed techniques for backtracking wave energy to its source (e.g. Mettlach *et al.* [7]); however, backtracking is not necessary for climate assessment. All that is required is a time series of directional wave spectra.

The phenomenon of climate change can be gleaned from 46042 records obtained at the National Oceanographic Data Center, but the change is reliably found only after careful data culling. In Fig. 5, we see the 1,630 hours in which the peak wave period $1/f_p$ in the C_{11} spectrum was 20 seconds or greater, *and* peak wave direction $\alpha_1(f_p)$ was between 150°N and 330°N, *and* the spreading function at the peak of the spectrum $r_1(f_p)$ was least .8. This data culling produces heights and directions that appear reasonable and accurate. Regression lines through the data indicate that long-period swell waves are increasing in size by +.041 m/yr for H_{m0} and +.023 m/yr for H_{low}. Center of storm activity is drifting slowly south at -.509°/yr. We suspect that the spreading function value $r_1(f_p)$ has declined .02/yr owing to underlying changes in payload and Hippy mode.
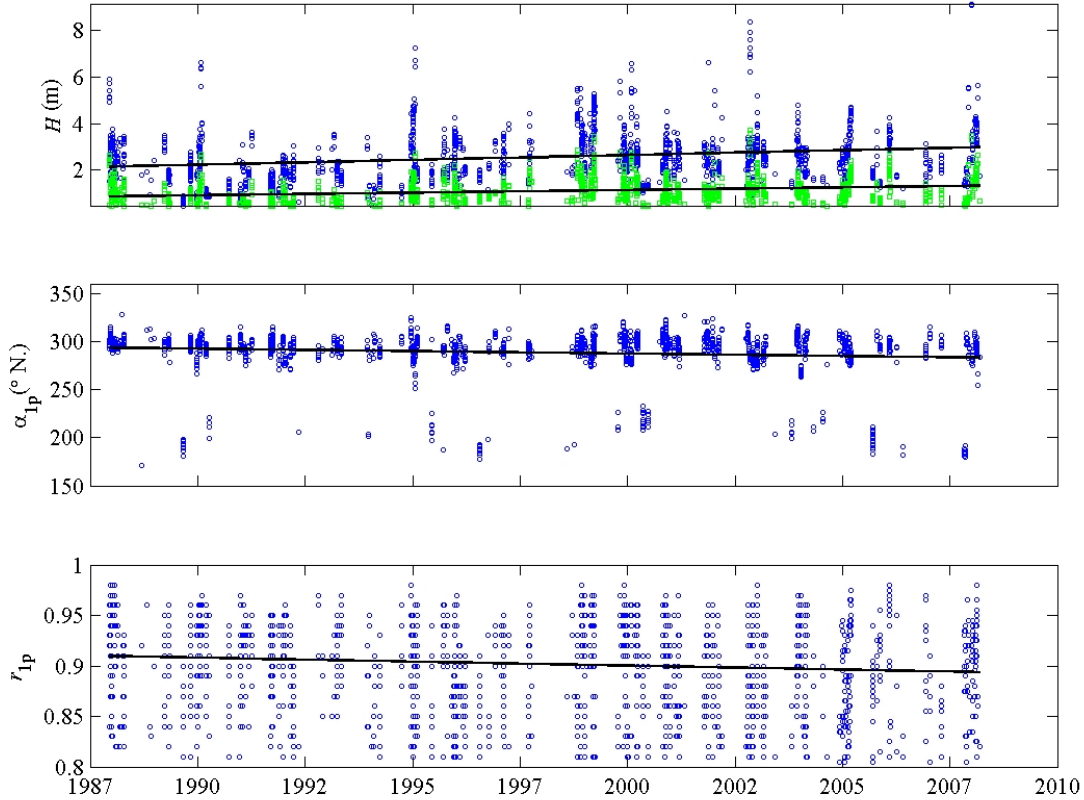

Fig.5: Station 46042 wave records for 1,630 hours in which peak wave period is 20 seconds or greater. In the upper panel, blue is H_{m0}, green is H_{low}. The middle panel gives $\alpha_1(f_p)$. The bottom panel is $r_1(f_p)$

Wave directions, however, reveal decidedly real questions about the quality of data from the station. In Fig. 6, we show H_{m0} and H_{low} for all hours in the record with <u>non-zero energy at .05 hertz and below</u>. From September 3, 1987 to April 20, 2008, this amounted to 31,046 hours. In the lower panel, we see the primary wave direction α_1 at .05 hertz. The lower panel reveals three separate periods corresponding to Hippy mode and wave processor given in Table II. Prior to October 1994, the station reported not one 20-second wave direction coming from land; however, in displacement mode, as well as in acceleration mode with the DWPM, this is not the case. In addition, a careful look at the upper panel indicates that the density of spectra with 20-second or greater period energy was significantly affected by mode and processor. Erroneous directions and the change in the amount of low frequency wave energy in the spectra coincident with changes in Hippy mode, and to a lesser degree, in payload, require further analysis.

We suspect that a timing difference between displacement and slope measurements was introduced in the change from acceleration to displacement in October 1994, which resulted in a smearing of energy across direction bands, thus producing the errors in direction. However, a lag would not have affected wave height. The lower density of wave heights in region I gives the visual perception that wave heights increased markedly at the boundary from region I to II. This is not really the case, as we show in Figure 7.
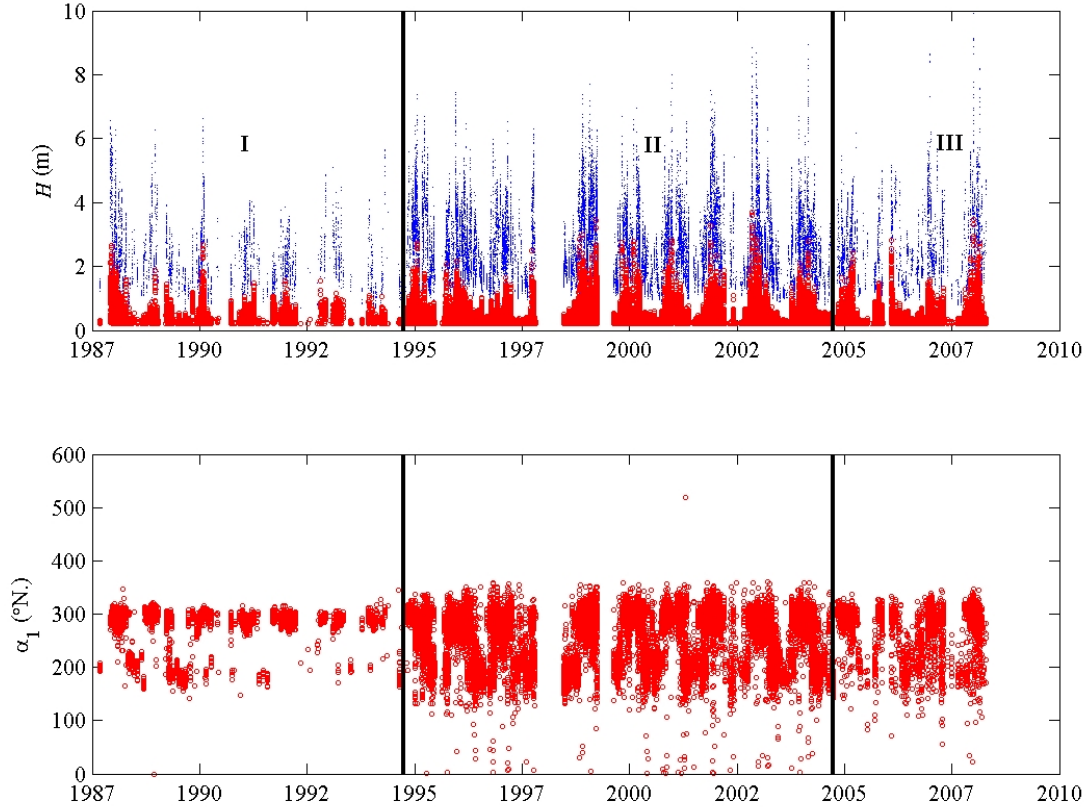
Fig.6: Station 46042 wave heights from all spectra with energy at or below 0.05 hertz.. In the upper panel, blue is H_{m0}, red is H_{low}. The lower panel gives $\alpha_1(f = .05Hz)$

Monthly averages reveal a change in response to waves. Average monthly wave heights of H_{m0} and H_{low} using all spectra in the record with energy at or below .05 hertz are plotted in the upper panel of Fig. 7. The lower panel gives the number of cases used in computing the average. The same discontinuities appear at October 1994 and October 2004, as in the previous graph. Clearly, Hippy mode and processor have had a direct influence on sensitivity, or oversensitivity, of the station to low frequency wave energy. Slope of the regression line through H_{m0} indicates an increase of 0.021 m/yr; however, there is a slight decline in H_{low} of -0.001 m/yr, which is so small as to be ignored as any kind of climate dynamics signal. This decline is likely just an artifact of the changes to wave system. Reflection of a true climate signal using 46042 requires, at the least, significant, thoughtful data culling, as is done in obtaining the results in Figure 5. However, since the raw high-resolution measurements onboard the buoy have been lost, there is little that can be done to re-analyze — spectra cannot be recomputed. The high volume of these measurements has precluded transmission via satellite. Once used, raw measurements are overwritten by the next hour of data acquisition.
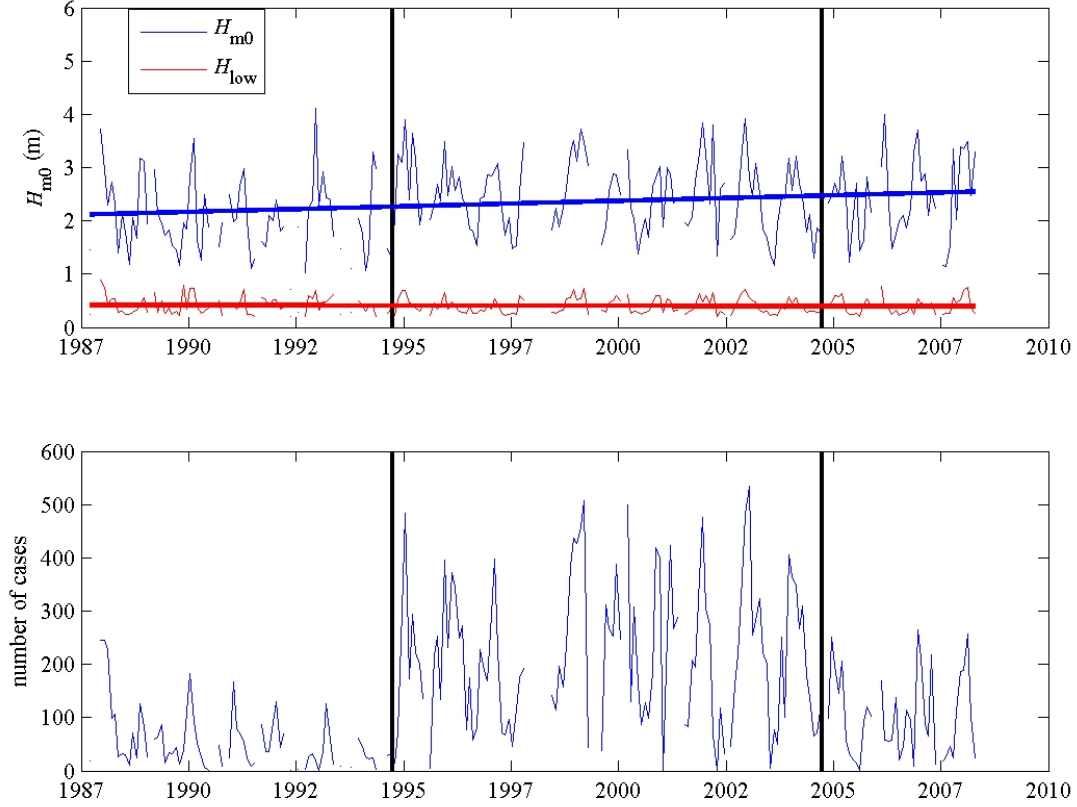
Fig.7: Station 46042 wave records. In the upper panel, blue is monthly H_{m0}; red is H_{low}, and first order regression curves. The lower panel is number of cases for the month with wave frequency equal to or less than .05 Hz.

IV. DISCUSSION AND CONCLUSIONS

   In this paper, it was shown that one of NDBC's buoys has provided a rich source of information for climatologists focusing on temperatures in Bering Sea. Examining the long record at 46035, arguably the station in the harshest environment in the NDBC network, we have found no major problems. Station 46035 has operated relatively well in a remote location, but a critical one owing to the pronounced climate signal there, one of the greater climate signals on the earth's surface.

   In our examination of wave measurements from 46042, presumably the flagship NDBC station for deep water wave measurement along the west coast of the United States, we have uncovered subtle discontinuities that cast doubt on the quality of the record. Culling all but the best measurements based on an understanding of the underlying technique for deriving directional wave spectra, we have been able to arrive at the tenuous suggestion that wave activity in the Pacific Ocean is actually increasing, and this conclusion applies to the entire Pacific because 20-second wave energy propagates for thousands of mile. This increase in wave energy is consistent with global-wide observations that the temperature of the lower atmosphere is on the rise, at least for the moment. Greater temperatures may be the basis for greater storm activity, and thus, increased swell waves. However, examination of the 46042 record indicates that it cannot be used confidently to prove or disprove the hypothesis of increased wave ac-

tivity from global warming. Obvious changes in the records also cast some doubt on other conclusions regarding increased Atlantic wave activity based on other NDBC wave stations equipped with the same variety of payloads, wave processers and frequency bands as the Monterey station. In fact, we must caution any users attempting to make conclusions regarding climate change from NDBC wave records ([8], [9], and [10]).

Nevertheless, we have shown the basic approach to take for future investigations of Pacific swell wave activity. Counting the number of 20-second wave events each year is all that is required, however, the scientific community must standardize the processing technique. If this is done and a high quality station is placed at Monterey for 20 years, it can be used essentially to watch the entire Pacific Ocean from a single place.

No amount of money today can buy us a 20-year record of wave heights for climate research beginning in 1988, and little can be done to recover corrupted or flawed records. Standard NDBC meteorological and oceanographic measurements are less problematic. NDBC has met many of the problems inherent in linking ocean and climate sciences. The location of 46042 is ideal for monitoring swell energy in the Pacific. We have shown that NDBC has overcome the engineering challenges of operating a buoy nearly continuously for over 20 years. Imperfections in the wave record from Monterey have certainly revealed a need to focus on basic climate monitoring principles if the wave data collected there are ever to be used properly for climate research.

NDBC always strives for the highest quality of data collected by its systems and stations through conducting stringent quality control and continuous improvements and upgrades of its data collection systems. We are highly confident that quality of data is high which makes the data valuable for various applications, such as forecast, warning, etc. However, it requires consistency of the data quality for climate study. It needs to carefully examine if a proposed improvement or upgrade of a collection system will have any impact on this.

In this preliminary study, only two buoy stations were used as examples to examine the quality of NDBC's data for climate study. It is fully understood that more detailed examination of various data collection principles and systems is needed. In addition, analyzing data from more stations and various environmental conditions will be able to provide more insight of what is discussed in this paper and further information about quality of climate data.

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